

PCT

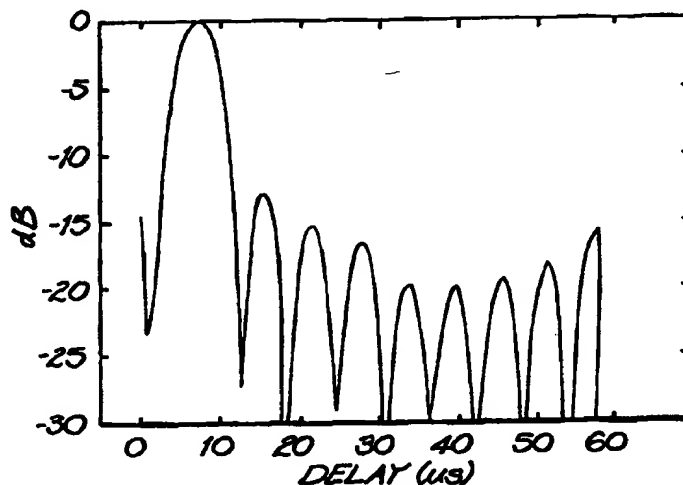
WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification⁶ : H04L 25/02</p>	<p>A1</p>	<p>(11) International Publication Number: WO 98/38772 (43) International Publication Date: 3 September 1998 (03.09.98)</p>
<p>(21) International Application Number: PCT/FI98/00159 (22) International Filing Date: 23 February 1998 (23.02.98) (30) Priority Data: 14889/97 25 February 1997 (25.02.97) AU (71) Applicant (for all designated States except US): NOKIA TELECOMMUNICATIONS OY [FI/FI]; Keilalahdentie 4, FIN-02150 Espoo (FI). (72) Inventor; and (75) Inventor/Applicant (for US only): WHITE, Peter, John [AU/AU]; 12 Jaylang Place, Figtree, NSW 2525 (AU). (74) Agent: KOLSTER OY AB; Iso Roobertinkatu 23, P.O. Box 148, FIN-00121 Helsinki (FI).</p>		<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published With international search report.</p>

(54) Title: CHANNEL IMPULSE RESPONSE ESTIMATION USING SINGULAR VALUE DECOMPOSITION



(57) Abstract

The present invention relates to the estimating of CIR (channel impulse response) and SINR (signal-to-interference-plus-noise ratio) in CDMA receivers. Particularly, the present invention is directed to a method of determining the channel impulse response (CIR) of a communication system, such as the CIR of radio channels of a digital mobile radio network (GSM network). In particular, the present invention relates to determining the CIR based on the reception of a known training sequence. The present invention also has application in interference cancellation and use in CDMA receivers. The present invention stems from the realisation that the problems associated with the prior art can be alleviated by initially transforming the matrix obtained by virtue of network analysis into a 'diagonal matrix' and then inverting the resultant diagonal matrix. A further invention is to multiply the reciprocal of the eigenvalue in the inverse by a decreasing number until the sidelobes are removed or so small that they have little effect.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

CHANNEL IMPULSE RESPONSE ESTIMATION USING SINGULAR VALUE DECOMPOSITION
FIELD OF INVENTION

The present invention relates to the estimating of CIR (channel impulse response) and SINR (signal-to-interference-plus-noise ratio) in CDMA receivers.

5 Particularly, the present invention is directed to a method of determining the channel impulse response (CIR) of a communication system, such as the CIR of radio channels of a digital mobile radio network (GSM network). In particular, the present invention relates to determining the CIR based on the reception of a known training sequence. The present invention also has application in

10 interference cancellation and use in CDMA receivers.

BACKGROUND

In order to determine CIR, a portion of the transmit signal must be known. For a GSM network, Synchronisation bursts (SB) are a useful portion of the signal. The SB are transmitted on at least one channel from every base station,

15 and they are transmitted in a regular pattern. Decoding of the GSM protocols is not necessary. Both the data in the SB and the pattern with which they occur is fixed and substantially identical for all base stations.

The advantage of using SB for determining the CIR is that they represent a relatively long, noise-like predetermined transmitted signal. Typically, 64 bits

20 are transmitted over a period of 237 μ sec. The determination of the CIR thus requires sufficient synchronisation to the bursts in the received signal to enable the extraction of the SB which is then processed to determine the CIR.

The processing is done by using estimation techniques. In order to estimate the CIR, a known training sequence is transmitted $S_{tx}(t)$, and this is

25 corrupted by a communications channel producing the received signal $S_{rx}(t)$. The problem in estimating the CIR is to determine tap-weights $\{\alpha\}$ of a FIR filter (which is used to approximate the CIR), so that the known $S_{tx}(t)$ after passing through the filter is as close as possible to the received signal $S_{rx}(t)$.

Given the that the transmitted Signal $S_{tx}(t)$ and the received signal $S_{rx}(t)$

30 is known, the CIR can be estimated from:

1. known samples of the transmitted signal $T_k = S_{tx}(t_0 + k\tau)$, $-N_c \leq k < N$ (note that $N + N_c$ samples represent the whole training sequence, the numbering has been arranged to start from the known clean samples of the received signal which occur N_c samples after the start of the training sequence.),

5 and

2. measured samples of the received signal $R_k = S_{rx}(t_0 + k\tau)$, $0 \leq k < N$ (the first N_c samples of the training sequence are assumed corrupted and are ignored).

The tap weights $\{\alpha_k\}$ are determined by simple correlation as

$$\alpha_k = \sum_{j=0}^{N-1} T_{j-k} R_j \quad 0 \leq k \leq N_c \quad (2.1)$$

10

This algorithm relies on the noise-like properties of the transmitted signal whereby its autocorrelation function should have low time sidelobes. The sidelobe performance of this algorithm, however, has been found to be limited
15 due to the correlation properties of the "clean" part of the training sequence and the fact that only partial correlations are performed for later weights.

US 5,473,632 estimates CIR by the use of a "least square approach", where the Complex Pulse Response (CIR) is predicted by minimising the square of the error between what the channel actually outputs and what the estimated
20 predicted model outputs. This approach gives rise to the equation at Column 6, line 35 of US 5, 473,632 which is known from various text books.

There is considered to be a problem with the US 5,473,632 approach. Basically, US 5,473,632 produces a matrix. The problem really relates to what is done to the matrix to calculate the CIR.

25 In US 5,473,632, referring to column 5 lines 27 to 61 and claim 2 thereof, a "factor α " is added to the matrix before the matrix is inverted, and then after the "factor α " is added, the matrix is inverted. In practice it has been found that the inversion of the matrix causes problems in calculating the CIR.

SUMMARY OF INVENTION

The present invention seeks to alleviate the problems experienced in determining CIR and SINR with prior art techniques.

In essence, the present invention stems from the realisation that the
5 problems associated with the prior art can be alleviated by initially transforming the matrix obtained by virtue of network analysis into a 'diagonal matrix' and then inverting the resultant diagonal matrix. Thus there is no "factor α " added.

An advantage of using a diagonal matrix is that it is possible to remove or ignore some eigenvalues (such as some of the small problematic
10 eigenvalues) and in this way avoid the magnified errors and noise of US 5,473,632 when the matrix is inverted.

Another advantage of using a diagonal matrix is attributable to the nature of a diagonal matrix and that is, the matrix can be inverted by inverting only the diagonal elements. This exposes the difficulty caused by small eigenvalues - they
15 lead to very large elements in the inverse.

However, by ignoring or removing some eigenvalues a further problem may develop as shown in figure 1, that is the production of large sidelobes.

Thus, the present application discloses a still further invention which is directed to alleviating the problem of the production of large side lobes.

20 This further invention is considered an improvement on the invention noted above and is based on, not discarding small eigenvalues (which is the approach noted above) but instead to multiply the reciprocal of the eigenvalue in the inverse matrix by a decreasing number until the sidelobes are removed or so small that they have little effect.

25 DETAILED DESCRIPTION AND BEST MODE

A preferred embodiment of the inventions disclosed above will now be described with reference to the accompanying drawings, in which:

Figure 1 illustrates CIR estimated using the algorithm disclosed in US 5,473,632 using $\epsilon = 200$, S/N = 0dB,

30 Figure 2 illustrates CIR estimated using the algorithm disclosed in US 5,473,632 using $\epsilon = 400$, no noise,

Figure 3 illustrates CIR estimated using SVD and including 10 largest

eigenvalues,

Figure 4 illustrates CIR estimated using SVD and including 16 largest eigenvalues,

Figure 5 illustrates CIR estimated using SVD and including 25 largest eigenvalues,

Figure 6 illustrates CIR estimated using SVD and including 36 largest eigenvalues,

Figure 7 illustrates CIR estimated using SVD and using ramping function with $n_1=4$, $n_2=25$ and no added noise,

10 Figure 8 illustrates CIR estimated using SVD and using ramping function with $n_1=4$, $n_2=25$ S/N - 0dB,

Figure 9 illustrates CIR estimated using SVD and using ramping function with $n_1=4$, $n_2=20$ no noise,

15 Figure 10 illustrates CIR estimated using SVD and using ramping function with $n_1=4$, $n_2=20$ S/N = 0dB,

Figure 11 illustrates CIR estimated using SVD and using ramping function with $n_1=1$, $n_2=25$ no noise,

Figure 12 illustrates CIR estimated using SVD and using ramping function with $n_1=1$, $n_2=25$ S/N = 0dB,

20 Figure 13 illustrates CIR estimated using SVD and using ramping function with $n_1=1$, $n_2=64$ no noise (Note dB scale to -60dB),

Figure 14 illustrates CIR estimated using SVD and using ramping function with $n_1=1$, $n_2=64$ S/N - 40dB,

25 Figure 15 illustrates CIR estimated using SVD and using ramping function with $n_1=1$, $n_2=25$ S/N = 40dB,

Figure 16 illustrates CIR estimated using SVD and using ramping function with $n_1=1$, $n_2=25$ Path 1 at $6.9\mu\text{s}$ 0dB, Path 2 at $18.5\mu\text{s}$ -20dB, Path 3 at $29.5\mu\text{s}$ -10dB no noise,

30 Figure 17 illustrates CIR estimated using SVD and using ramping function with $n_1=1$, $n_2=25$ Path 1 at $6.9\mu\text{s}$ -10dB, Path 2 at $18.5\mu\text{s}$ 0dB, Path 3 at $29.5\mu\text{s}$ 0dB, Path 4 at $40.4\mu\text{s}$ -6dB S/N - 20dB, and

Figure 18 illustrates CIR estimated using SVD and using ramping

function with $n_1=1$, $n_2=25$ Path 1 at $6.9\mu\text{s}$ 0dB, Path 2 at $12.2\mu\text{s}$ 0dB no noise.

One method of estimating the tap weights is to determine the weights which predict a received signal most closely matching the measured signal.

Given the transmitted Signal $S_{tx}(t)$ with known samples:

$$5 \quad T_k = S_{tx}(t_0 + k\tau), \quad -M \leq k < N$$

(M is the assumed extend of the CIR - the number of "dirty" samples)

and a received Signal $S_{rx}(t)$ with measured samples:

$$R_k = S_{rx}(t_0 + k\tau), \quad 0 \leq k < N$$

The desired FIR tap weights (α_k) are estimated by requiring that the
 10 cumulative square error between the measured received signal and the estimate of the received signal (i.e. the known transmitted signal passed through the FIR approximating the channel) is minimised,
 i.e. minimise

$$\varepsilon^2 = \sum_{k=0}^{N-1} \left| R_k - \sum_{j=0}^{M-1} \alpha_j T_{k,j} \right|^2 \quad (2.2)$$

15 this may be reduced to the following system of simultaneous equations

$$\sum_{j=0}^{M-1} \left(\alpha_j \sum_{k=0}^{N-1} T_{n-j} \overline{T_{n-i}} \right) = \sum_{k=0}^{N-1} R_k \overline{T_{k-i}} \quad 0 \leq i < M \quad (2.3)$$

or using matrix notation

$$Ac = TR \quad (2.4)$$

where the matrix A is the MxM correlation matrix given by

$$a_{i,j} = \sum_{n=0}^{N-1} T_{n-j} \overline{T_{n-i}} \quad (2.5)$$

20

and T is the MxN matrix of conjugated delayed signals

$$t_{i,j} = T_{i,j} \quad 0 \leq i \leq M \quad 0 \leq j \leq N \quad (2.6)$$

and vector c is the required CIR (α_k)

Note that simple correlation corresponds to

25

$$c = TR \quad (2.7)$$

The matrix equation (2.4) has the formal solution

$$c = (A^{-1}T)R \quad (2.8)$$

showing that the CIR may be determined from the samples of the received signal using a simple matrix multiplication.

Least Squares Estimation using US 5,473,632

- 5 Equation (2.8) equates to the equation disclosed in US 5,473,632 at col 6, line 35.

The complication with the use of this equation arises when the equations are solved directly in that they are generally poorly conditioned. In fact, it has been found that for the GSM training sequence in the SB the eigenvalues of the
10 matrix vary over a range exceeding 10^{10} . This is considered to make the inverse of the matrix extremely susceptible to roundoff error and the result extremely susceptible to noise on the measured signal.

It has been found that by applying conventional techniques to invert this matrix or to solve the equations, the results are not considered useful, even
15 when using IEEE double precision arithmetic.

US 5,473,632 discloses an algorithm which stabilises the inversion of the matrix and produces results reasonably resilient to noise. US 5,473,632 estimates the CIR by

$$c = ((A + \epsilon I)^{-1}T)R \quad (2.9)$$

- 20 where I is the identity matrix and ϵ is a constant (they call a noise term). This equation equates to the equation disclosed in US 5,473,632 at col. 6, line 44. The results of using this algorithm follow:

The performance of this algorithm critically depends on the choice of the variable ϵ . For the matrix A which has diagonal elements with magnitude 192,
25 the following figures show the performance of US 5,473,632 algorithm using difference values of ϵ in determining a CIR consisting of a single path.

Referring to Figures 1 and 2, for example, it can be seen that there is a trade-off between the resolution (width of the main lobe) and the noise performance. The sidelobe level of approximately -18dB seems a characteristic
30 of this algorithm.

We achieved a best comparable performance by using $\epsilon \equiv 100$, and on

this basis comparisons with US 5,473,632 are made.

Least Squares Estimation using SVD

In the present invention, we have chosen to apply the use of Singular Value Decomposition (SVD) to the poorly conditioned matrix for performing
5 least squares estimation. In this way, it has been found that we transform the matrix that is to be inverted to a diagonal matrix and then the new created diagonal matrix is inverted.

Using the SVD the matrix A (which is positive definite) may be represented by

$$10 \quad A = USV^T \quad (2.10)$$

where U and V are orthogonal and S is diagonal. In fact the diagonal elements of S are the eigenvalues (all positive) of A and these are arranged in decreasing order:

$$s_{1,1} \geq s_{2,2} \geq \dots \geq s_{n,n} \quad (2.11)$$

15 If the matrix is singular, some of these are zero. The inverse of A is then

$$A^{-1} = VS^{-1}U^T \quad (2.12)$$

where S^{-1} is formed by inverting the (diagonal) elements of S. The effects of a poorly conditioned matrix are clear here, the (almost zero) eigenvalues are inverted and produce an extremely large contribution to the inverse. These
20 amplify the noise.

Traditional SVD techniques only invert some of the eigenvalues and stop at some point. Instead of placing $1/\lambda_i$ into the inverse of S, the present invention uses zero instead. The performance of these techniques along with others are evaluated below.

25 The coefficients in the matrix in equation (2.8) are purely functions of the known training sequence, hence they can be computed beforehand. This matrix can be inverted once and then the solution at any time requires a matrix multiplication. Thus to obtain the CIR estimate from a set of signal samples requires $M * N$ complex multiplications and $M * (N-1)$ complex additions, a total
30 of $6 * M * N + 2 * M * (N-1)$ operations.

The application of SVD to the overdetermined least squares problem requires only including the contribution from the N largest eigenvalues in the

pseudo-inverse of the matrix. In the case being modelled, the matrix has dimension 64, hence N is in the range 1 to 64. The following plots show the performance of the SVD algorithm for $N = 10, 16, 25, 36$. The effect of increasing the number of eigenvalues is to increase the resolution of the estimator, that is reducing the width of the main lobe.

Although not shown, simulations were performed which showed that the noise performance degrades rapidly in the range of 10 to 20 eigenvalues.

The present SVD approach should yield good performance in noise as the rank of the pseud-inverse is minimised. The most bothersome aspect of the results is the persistent time sidelobes at approximately -13dB. By analogy with Fourier theory, where a truncated time waveform will give frequency sidelobes of -13dB, it was discovered that the ramping down of the contribution from successive eigenvalues instead of simply cutting off after a certain number proved very beneficial in providing control over the time sidelobes.

A number of ramping functions may be used such as Bartlett, Blackman-Harris, Poisson, Riesz, Hamming, Kaiser-Bessel, Lanczos, Tukey and other well known windowing functions. The function chosen in this embodiment has been derived from the Hanning window although the raised cosine ramp defined as below proved most successful:

$$w_i = \begin{cases} 1 & i \leq n_1 \\ 0.5 \left(\cos \left(\frac{i-n_1}{n_2-n_1} \pi \right) + 1 \right) & n_1 < i \leq n_2 \\ 0 & i > n_2 \end{cases} \quad (2.13)$$

where w_i weight applied to the contribution from the i th eigenvalue. As an example, Figure 7 shows the effect of $n_1=4, n_2=25$.

Note that the -13dB sidelobes have been reduced to approximately -22dB (already significantly better than the performance of US 5,473,632). The width of the main lobe is narrower than the $\epsilon=100$ US 5,473,632 algorithm with lower sidelobes. The performance with a S/N ratio of 0dB is shown in figure 8.

This performance is similar to that achieved with the $\epsilon=100$ US 5,473,632 solution, however note that the main lobe is narrower, this will degrade this noise performance.

Noise performance can be improved at the expense of the lobe width, as illustrated in Figures 9 and 10 which have $n_1=4$, $n_2=20$.

Considerable trials have taken place to find a satisfactory solution. The goals were:

- 5 • greater than 20dB dynamic range (preferably 25dB) to give a significant edge over the performance of US 5,473,632
- noise performance similar to correlation at S/N - 0dB. (This says that we don't want the solution to unnecessarily magnify the noise contributions).

10 The results determined from the above uses the weighting factors
obtained with $n_1=1$, $n_2=25$ and the performance is shown in figures 11 and 12.

Performance of the present algorithm on more complicated CIR's will be shown shortly. It is interesting to see how much dynamic range the ramping algorithm can provide as illustrated in the example shown in Figure 13.

15 This example is extremely sensitive to noise. Figure 14 shows the performance with S/N = 40dB. Note that even this small amount of noise is greatly magnified. This same amount of noise produces no perceptible noise on the preferred results as determined above and as shown in Figure 15.

Figures 16 and 17 illustrate the results for some more complex CIR's.

20 It has also been found that the present embodiment has the ability to enable the algorithm to discriminate between peak, and Figure 18 shows close peaks split with time separations greater than about 5 μ s.

Matrix inversion as described above is also required when estimating the channel impulse response vector \mathbf{h} in context of interference cancellation

$$25 \qquad \Phi h = \Psi \quad (2.14)$$

where Φ is the crosscorrelation matrix between locally generated signals and Ψ is the crosscorrelation matrix between locally generated signals and the received signal. The principles and method as described above are equally applied in this situation.

30 Similarly, in interference limited environment CDMA is applied usually using optimum combining of signals received from multiple sensors (antenna array). Optimum combining maximises the signal-to-interference-plus-noise

ratio (SINR). The weight vector for the antenna array to maximise SINR is obtained, for example from

$$w = \alpha R^{-1} u_d^* \quad (2.15)$$

where w is the weight vector for antenna elements, α is a constant, R is the
5 received interference-plus-noise correlation matrix, and u_d^* is the conjugate of
the desired signal vector. We have found an efficient way of getting the weight
vector by first calculating the CIR. Some optimum combining techniques
calculate first the CIR (and the noise covariance matrix Q) which is then used in
multidimensional MLSE to combine signals from the antenna array. Usually the
10 matrix inversion is problematic in mobile radio channels. The embodiment
as described above can be applied directly to matrix inversion.
To obtain the weight vectors or employ the inverse of Q to optimally combine the
signal.

In summary, whilst alternatives and variants are intended to be
15 encompassed by the present application, the preferred implementation of the
inventions disclosed is to generate a CIR using the matrix multiplication as
specified in equation (2.8) and to then use SVD to determine the inverse of the
matrix A . The eigenvalues included in the inverse are ramped (weighted)
according to equation (2.13) with $n_1=1$, $n_2=25$.

CLAIMS:

1. A method of estimating a channel impulse response (CIR) of a communication system for use by an estimated predicted model of a communication system, the method comprising the steps of:
 - predicting the CIR by minimising the square of the error between a measured received signal and a predetermined estimate of said received signal, said estimate being based on an approximation of a radio channel;
 - generating a first matrix form of said CIR;
 - transforming said first matrix to a diagonal matrix; and
 - inverting said diagonal matrix.
2. A method as claimed in claim 1, whereby the diagonal matrix is obtained by applying Singular Value Decomposition (SVD) to the first matrix.
3. A method as claimed in either claim 1 or claim 2, comprising the further step, following the step of inverting, of ramping down the contribution of excessive eigenvalues occurring in the inverted diagonal matrix.
4. A method as claimed in claim 3, whereby a windowing function is used to ramp down excessive eigenvalues.
5. A method as claimed in claim 4, whereby any one of Bartlett, Blackman, Harris, Gaussian, Poisson, Riesz, Hanning (raised cosine), Kaiser-Bessel, Lanczos, Tukey or other similar known windowing functions are used to ramp down said excessive eigenvalues.
6. A method as claimed in any one of the preceding claims, when used in a GSM network, interference cancellation or CDMA receivers.

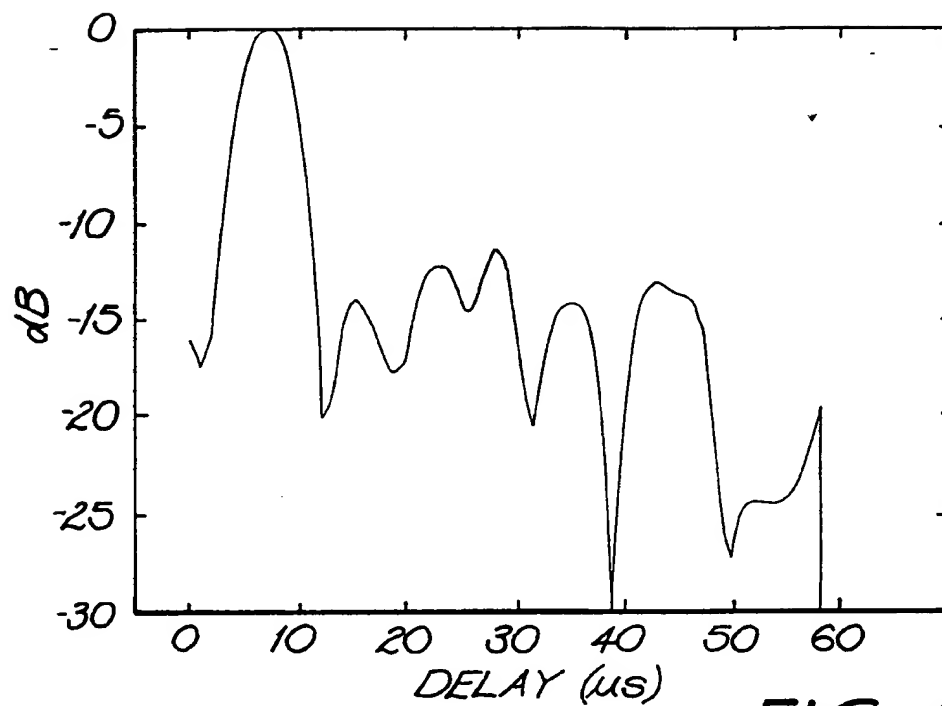


FIG. 1

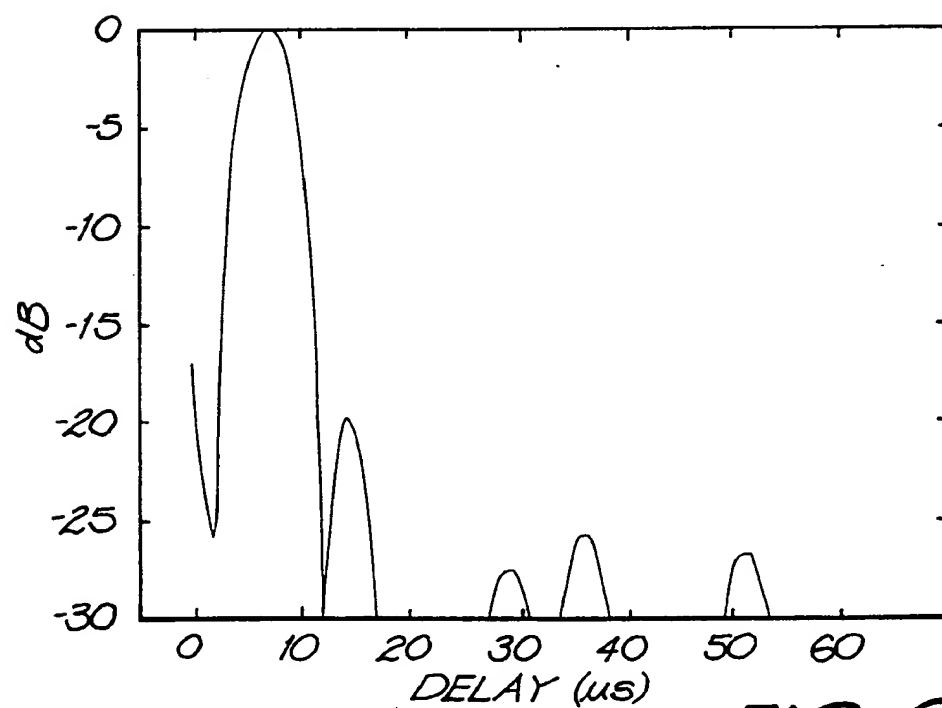
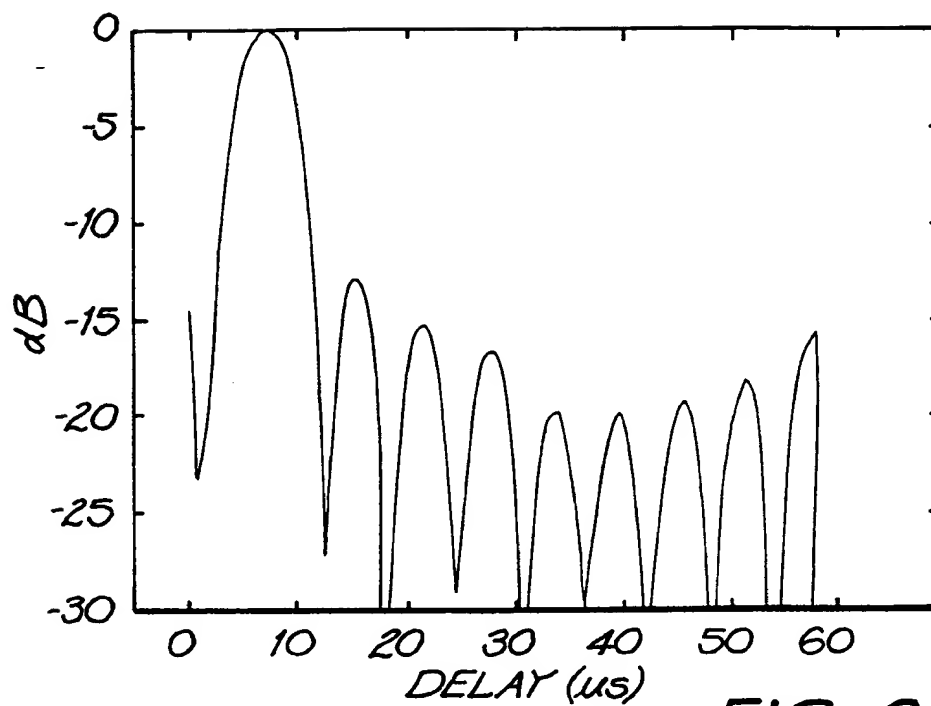
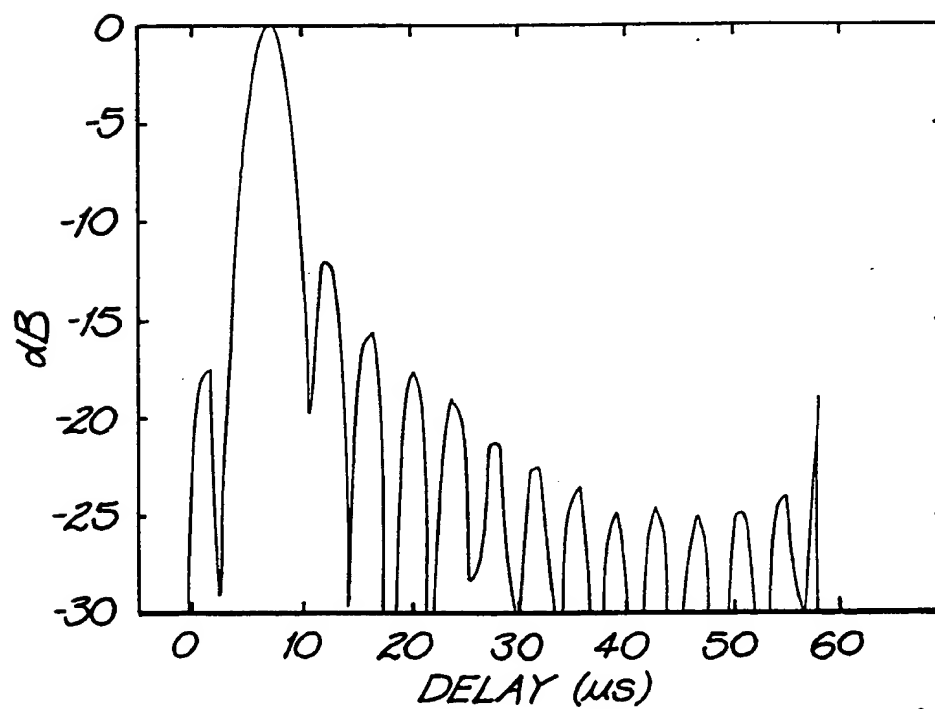
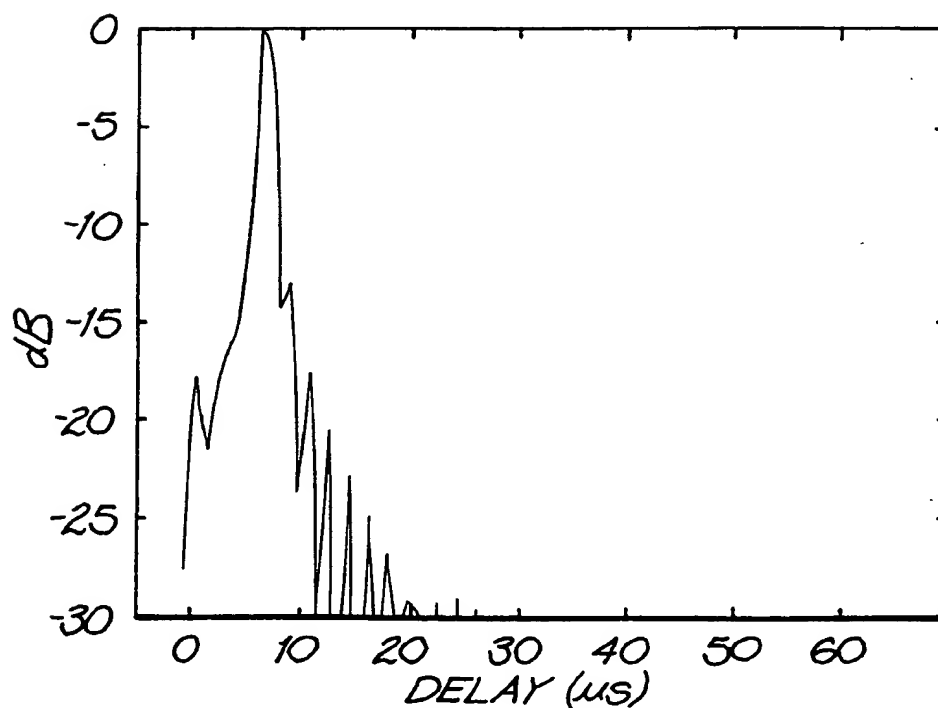
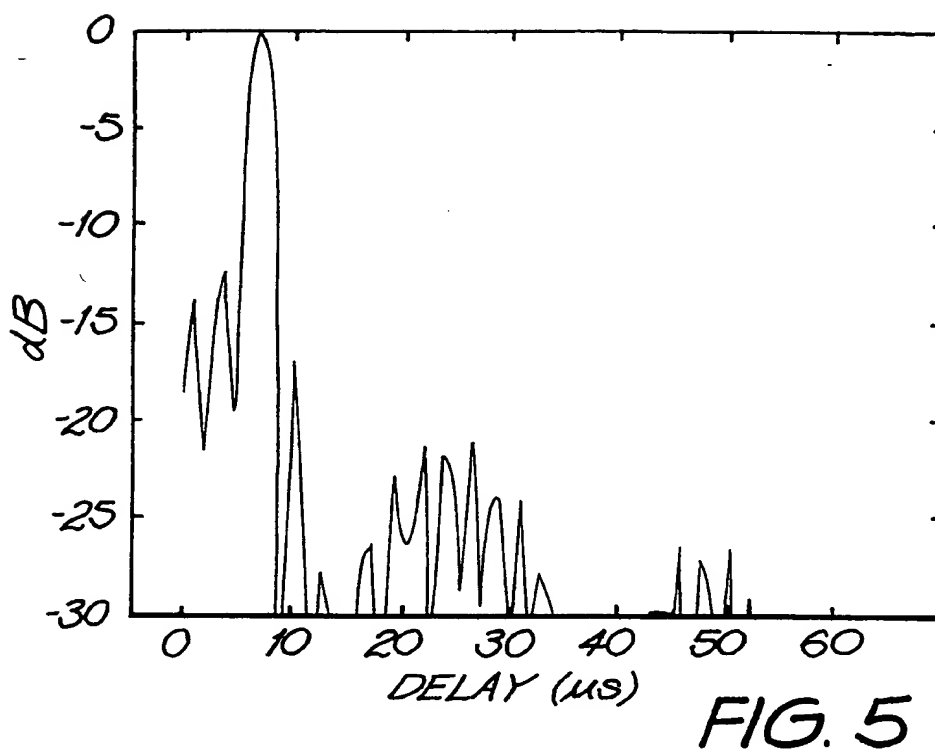


FIG. 2

**FIG. 3****FIG. 4**



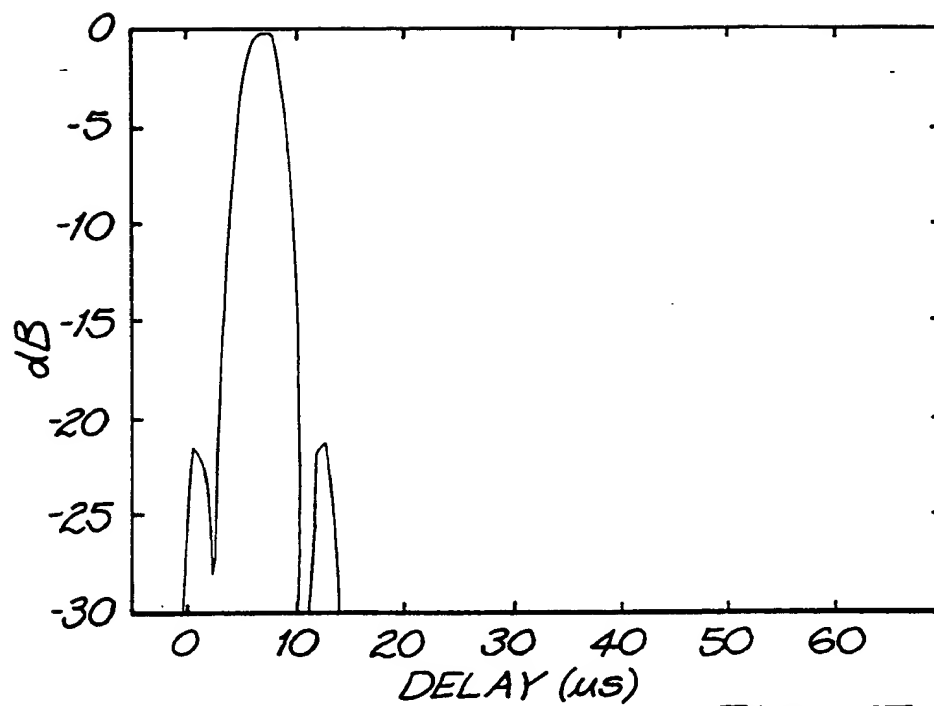


FIG. 7

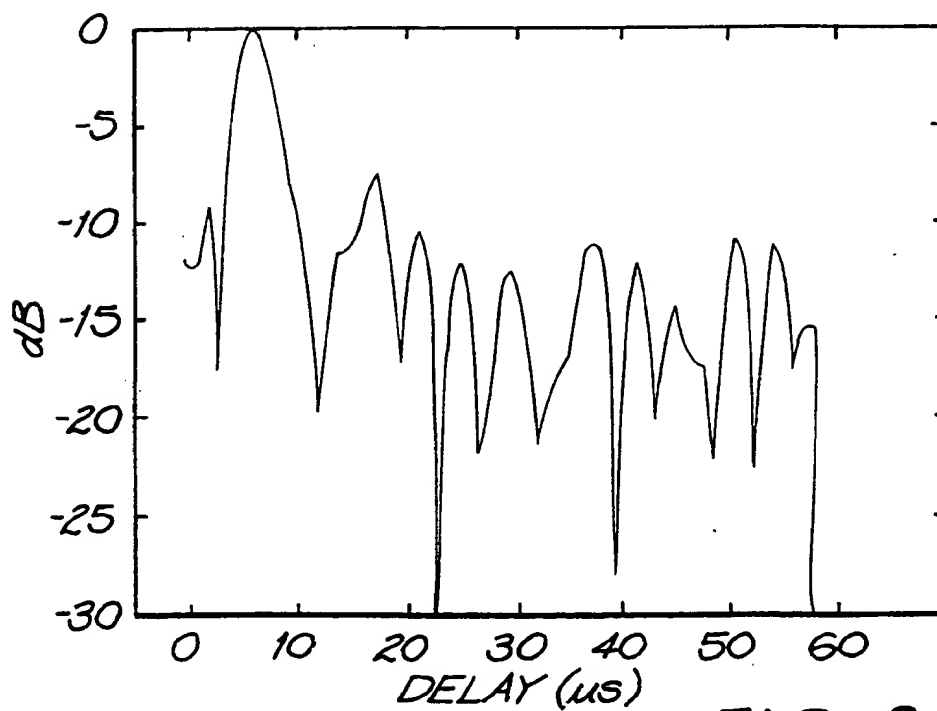


FIG. 8

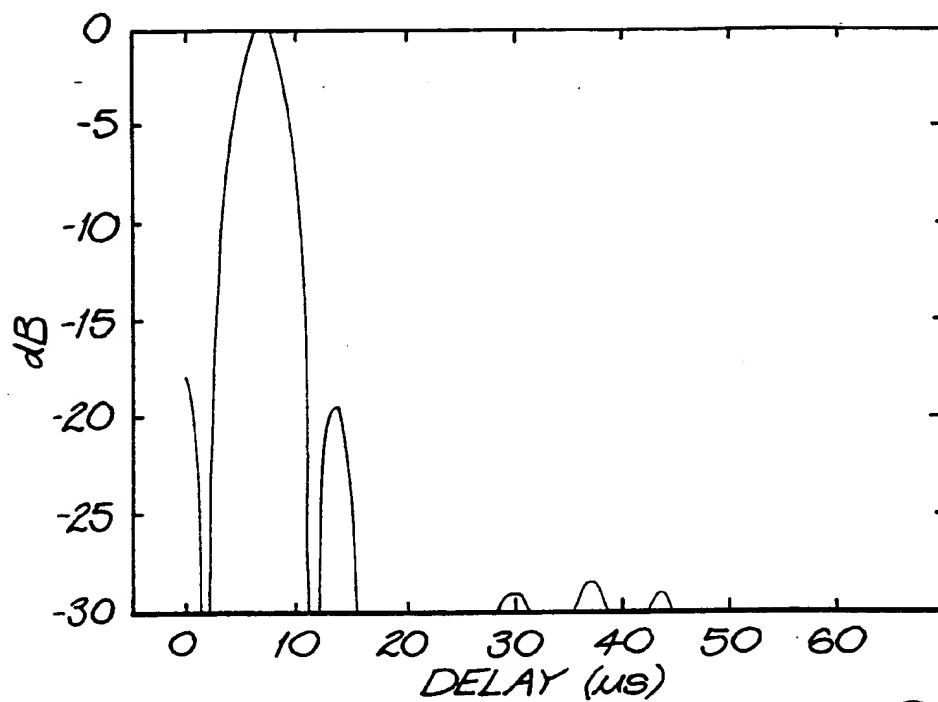


FIG. 9

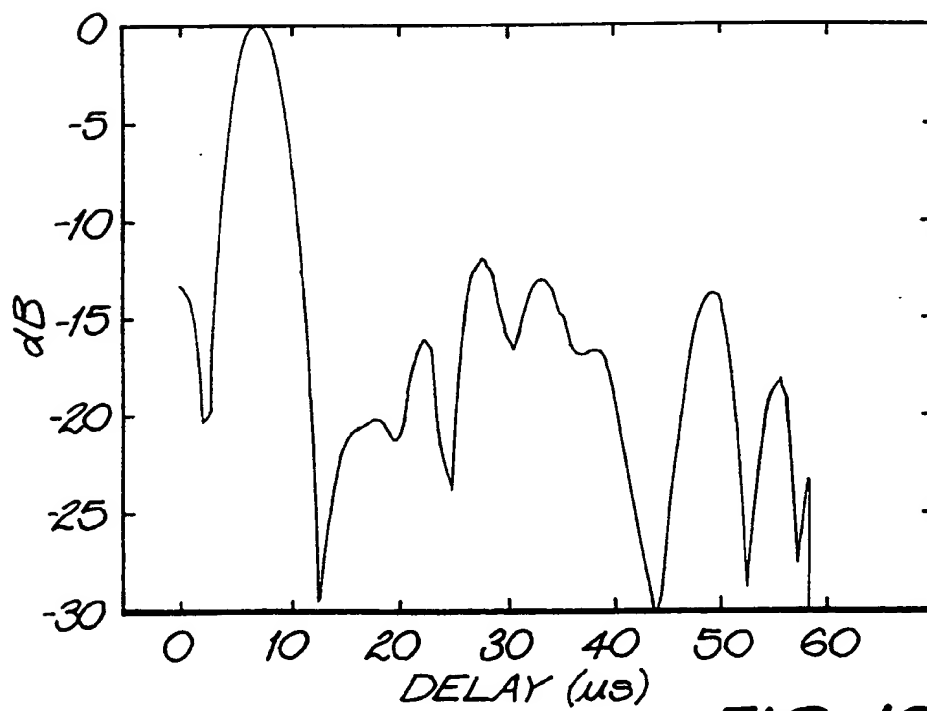
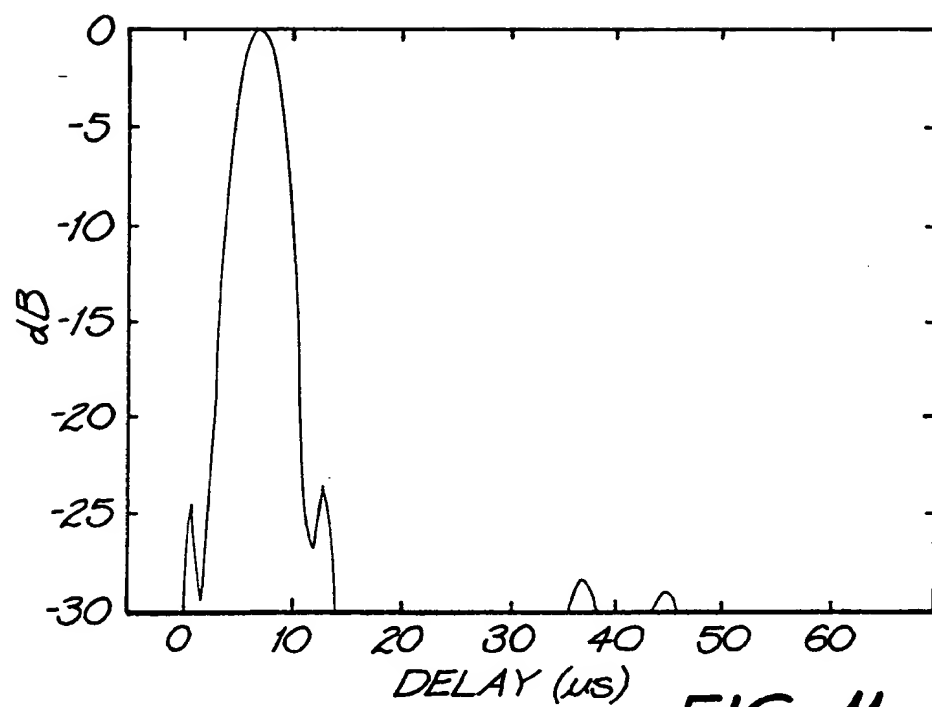
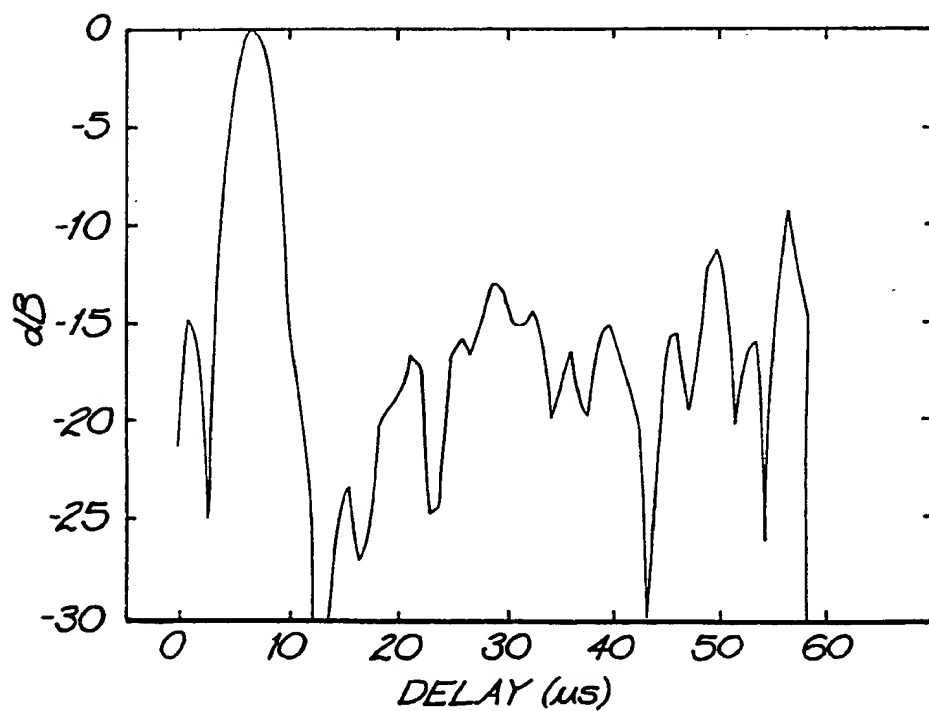
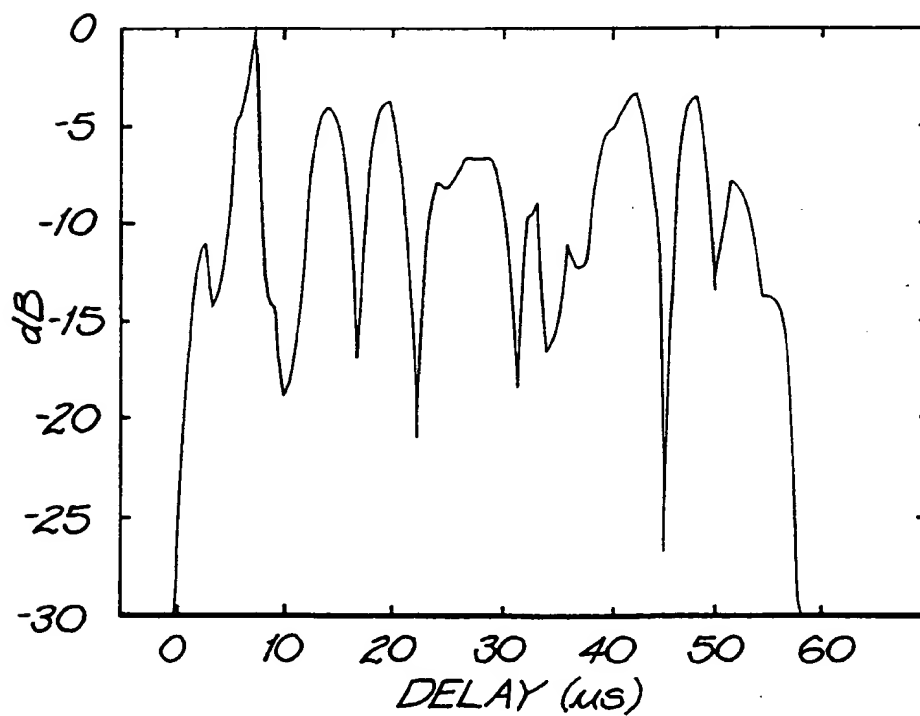
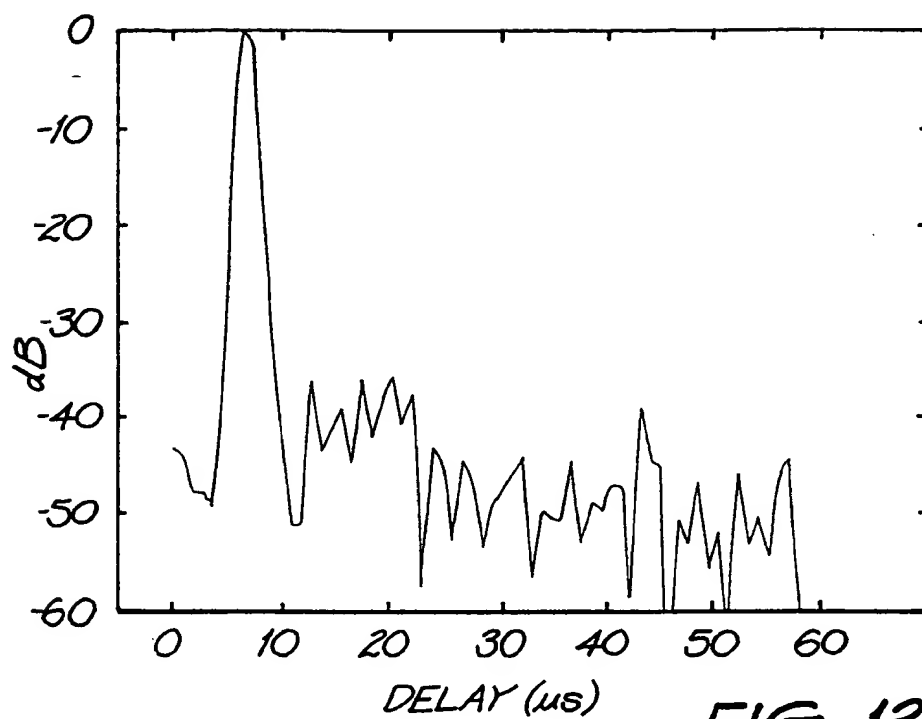


FIG. 10

**FIG. 11****FIG. 12**



8/9

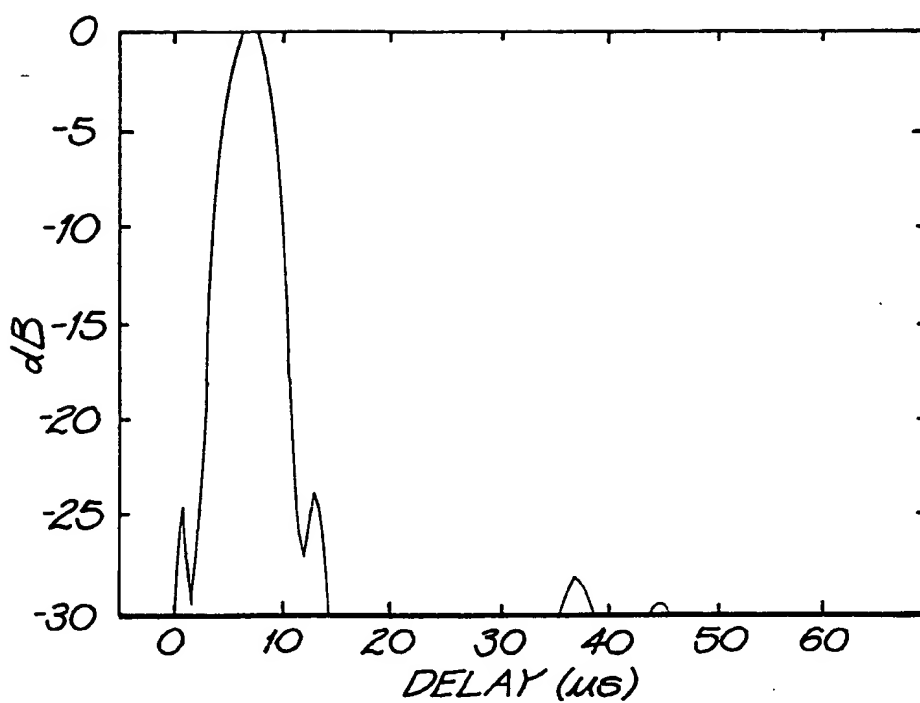


FIG. 15

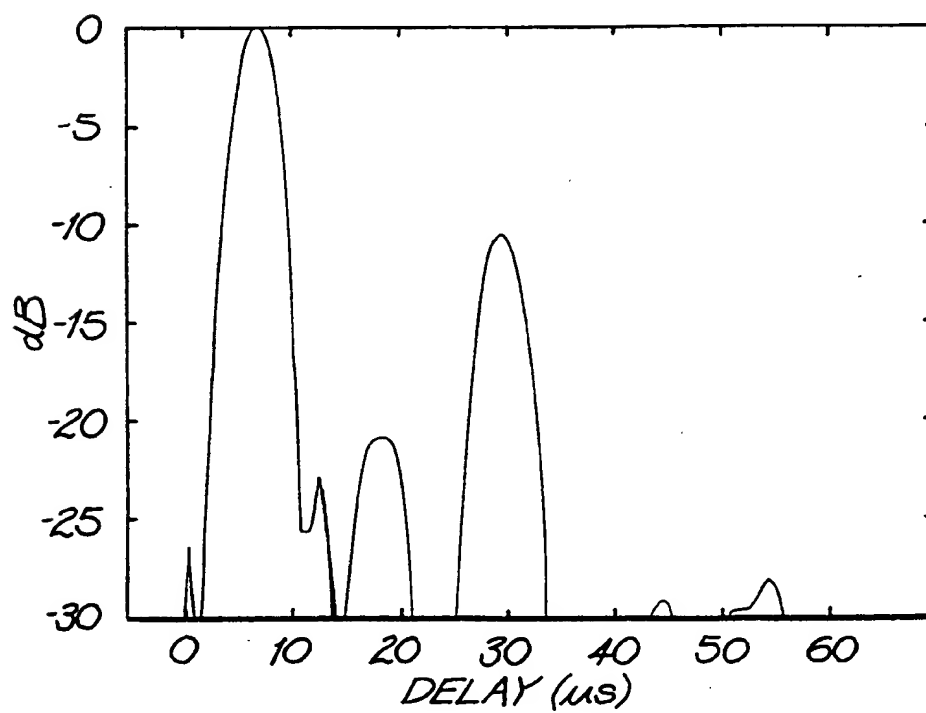
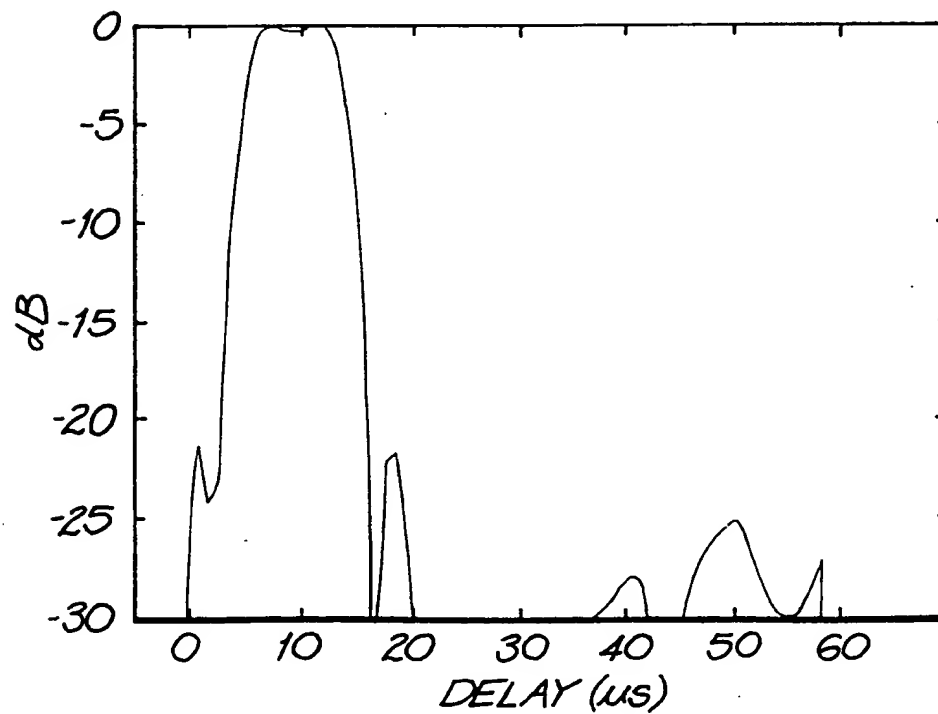
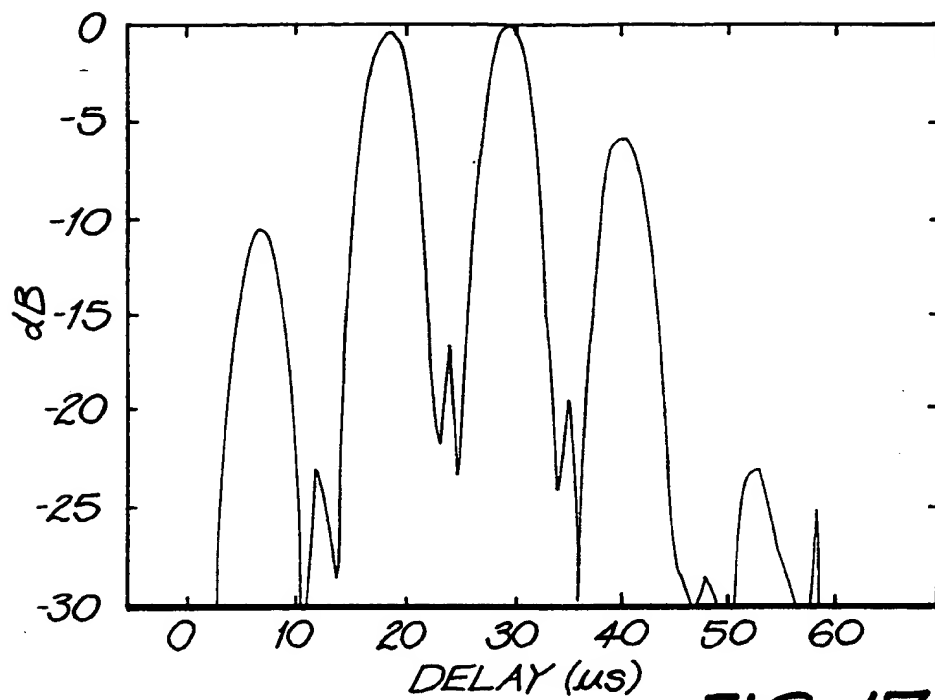


FIG. 16



INTERNATIONAL SEARCH REPORT

International Application No.

PCT/FI 98/00159

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L25/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
----------	------------------------------------------------------------------------------------	-----------------------

X	<p>EDFORS O ET AL: "OFDM CHANNEL ESTIMATION BY SINGULAR VALUE DECOMPOSITION" 1996 IEEE 46TH. VEHICULAR TECHNOLOGY CONFERENCE, MOBILE TECHNOLOGY FOR THE HUMAN RACE ATLANTA, APR. 28 - MAY 1, 1996, vol. VOL. 2, no. CONF. 46, 28 April 1996, NEW YORK, US, pages 923-927, XP000593108 see abstract see page 924, paragraph III-A - page 926, paragraph III-B</p> <p style="text-align: center;">---</p> <p style="text-align: center;">-/--</p>	1-3,6
---	-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-------

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

28 April 1998

Date of mailing of the international search report

25/05/1998

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl.
Fax: (+31-70) 340-3016

Authorized officer

Koukourlis, S

INTERNATIONAL SEARCH REPORT

Int'l onal Application No
PCT/FI 98/00159

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>RAHMAN J ET AL: "Deconvolution and total least squares in finding the impulse response of an electromagnetic system from measured data"</p> <p>IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, APRIL 1995, USA, vol. 43, no. 4, NEW YORK, US, pages 416-421, XP002063705</p> <p>see page 416 - page 418, left-hand column</p> <p>see page 419, left-hand column, paragraph 2 - right-hand column, paragraph 1</p>	1-3,6
Y	<p>US 5 473 632 A (RIEDEL PETER ET AL) 5 December 1995</p> <p>cited in the application</p> <p>see the whole document</p>	1,2,6
Y	<p>ZWILLINGER D.: "Standard Mathematical Tables and Formulae, 30th edition" 1996, CRC PRESS, BOCA RATON, US XP002063709</p> <p>see page 129, paragraph 2.5.11 - page 130</p> <p>see page 131, paragraph 2.5.13</p> <p>see page 134, paragraph 2.5.16</p>	1,2,6
A	<p>US 5 209 237 A (ROSENTHAL FELIX) 11 May 1993</p> <p>see abstract</p> <p>see column 8, line 55 - column 9, line 10</p> <p>see column 11, line 22 - line 41</p>	1-3
A	<p>US 4 945 502 A (KWON HEEMIN ET AL) 31 July 1990</p> <p>see column 2, line 52 - column 3, line 2</p> <p>see column 5, line 52 - column 6, line 24</p>	1-5
A	<p>VAN DER VEEN A L ET AL: "Singular value analysis of space-time equalization in the GSM mobile system"</p> <p>1996 IEEE INTERNATIONAL CONFERENCE ON ACOUSTICS, SPEECH, AND SIGNAL PROCESSING CONFERENCE PROCEEDINGS (CAT. NO.96CH35903), 7 - 10 May 1996, NEW YORK, USA, pages 1073-1076 vol. 2, XP002063706</p>	1-3,6
A	<p>BARTON M ET AL: "Reduced-rank least squares channel estimation"</p> <p>IEEE TRANSACTIONS ON ACOUSTICS, SPEECH AND SIGNAL PROCESSING, vol. 38, no. 8, August 1990, NEW YORK, US, pages 1403-1410, XP002063707</p>	1-3
	-/--	

INTERNATIONAL SEARCH REPORT

International Application No
PCT/FI 98/00159

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>BARTON M: "Approximate sample variance analysis of exponential channel derived from SVD-based algorithm"</p> <p>IEE PROCEEDINGS I (COMMUNICATIONS, SPEECH AND VISION),</p> <p>vol. 136, no. 6, December 1989, UK,</p> <p>pages 381-384, XP002063708</p> <p>-----</p>	1-3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/FI 98/00159

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5473632 A	05-12-95	DE 4135953 A DE 59207590 D EP 0539750 A	06-05-93 09-01-97 05-05-93
US 5209237 A	11-05-93	CA 2080292 A,C EP 0524258 A JP 8017772 B JP 5505124 T WO 9115995 A DE 69122095 D DE 69122095 T	10-04-94 27-01-93 28-02-96 05-08-93 31-10-91 17-10-96 17-04-97
US 4945502 A	31-07-90	EP 0403641 A WO 9007750 A	27-12-90 12-07-90